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PULSE CODE MODULATION OF CO2 TEA LASER PULSE, (U)
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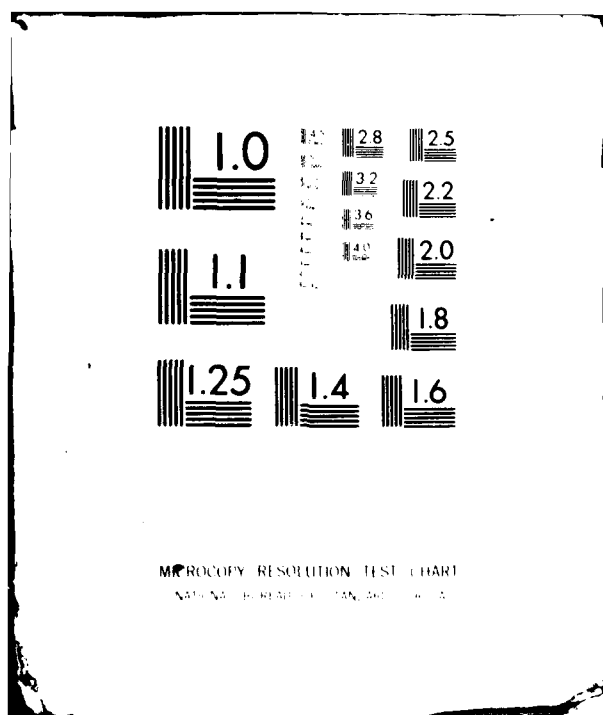
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PULSE CODE MODULATION OF CO_2 TEA LASER PULSE

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Introduction

The CO_2 TEA laser pulse is characterized by a gain-switched spike followed by a slow decaying tail. As a ranging waveform, the tail with its slow fall time does not contribute to the device's accuracy in ranging measurements. Elimination of this tail, with resulting increased energy in the spike, by optimization of the gas ratios, has been sought after. (1) On the other hand, utilization of the entire pulse to include the tail, leads to the concept of multifunctional applications such as range finding and Cooperative Battle-field Identification Friend or Foe (CBIFF). Application to CBIFF requirements would utilize the modulated tail by transferring coded telegrams to the target being interrogated.

The tail portion of the CO_2 TEA laser waveform is approximately 2 to 4 μ sec long. Depending on the achievable bandwidths for the modulator and receiver system, 10 to 100 bits of information can possibly be transmitted on a single CO_2 TEA laser pulse. A number of applications besides CBIFF can be explored including communication between two vehicles, data transmission, and precision ranging to name a few. In this report, the CO_2 TEA laser pulse tail is electro-optically (EO) modulated with a polarization sensitive switch capable of 5 MHz repetition rate and 100 nanosecond pulsewidths. With this capability, three operational modes can be realized; namely, 1) pulse shaping/sharpening of the gain-switched spike for precision ranging, 2) information transfer via modulation of tail, or 3) combining (1) and (2) on the same laser pulse. Mode #2 has been demonstrated and will be presented in this report.

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Experiment

Linearly polarized light in the plane of incidence passes through an uncoated ZnSe beam splitter placed at Brewster's angle (Fig. 1). Zero reflection for the plane polarized beam is observed while maximum reflection for the perpendicular polarized beam takes place. The polarizing angle θ_p is defined by Brewster's Law⁽²⁾

$$\tan \theta_p = n \quad (1)$$

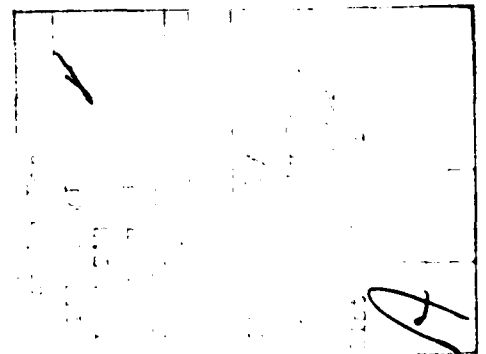
where n is the index of refraction for the beam splitter material ($n = 2.40$ for ZnSe).

The Pockels Cell (II-VI, Inc.) is an electrically-induced birefringent material whose index of refraction changes proportionally to the applied electric field. In a transverse-applied electric field configuration, the electro-optic retardation causes the polarized light to rotate its polarization about the optical axis such that one orthogonal component (say, Z' component) grows as it propagates along the propagation axis at the expense of the other orthogonal component (say, Y'). For CdTe, the electric field is applied along the cube diagonal $\langle 111 \rangle$ direction perpendicular to the propagation axis. The phase retardation experienced by the polarized light passing through the crystal with an applied voltage V is given below:

$$\Gamma = \frac{(\sqrt{3}\pi) n_o^3 r_{41}}{\lambda_o} \frac{V \ell}{d} \quad (2)$$

where n_o = index of refraction
 r_{41} = electro-optic coefficient
 λ_o = vacuum wavelength of laser beam
 ℓ = crystal length
 d = crystal width across which electric field is applied.

Using the following parameter values provided by Yariv,⁽³⁾ $n_o^3 r_{41} = 120 \times 10^{-12}$ m/V, and $\lambda_o = 10.6 \times 10^{-6}$ m, and crystal dimensions $d = 3$ mm, $\ell = 6$ cm, the calculated half-wave voltage ($\Gamma = 180^\circ$) is 2554 volts. The approximate half-wave voltage measured by the manufacturer is 2650 volts. The quarter-wave voltage for CdTe is, therefore, 1325 volts (based on manufacturer's estimate).



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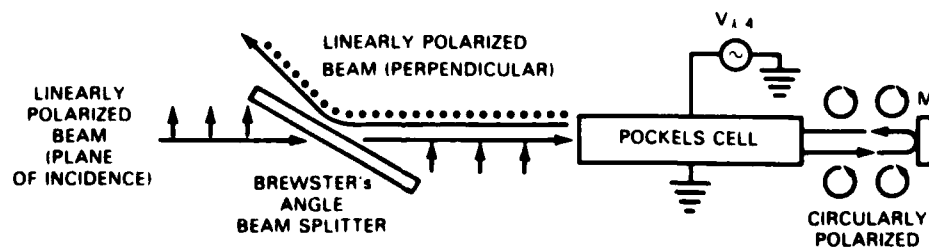
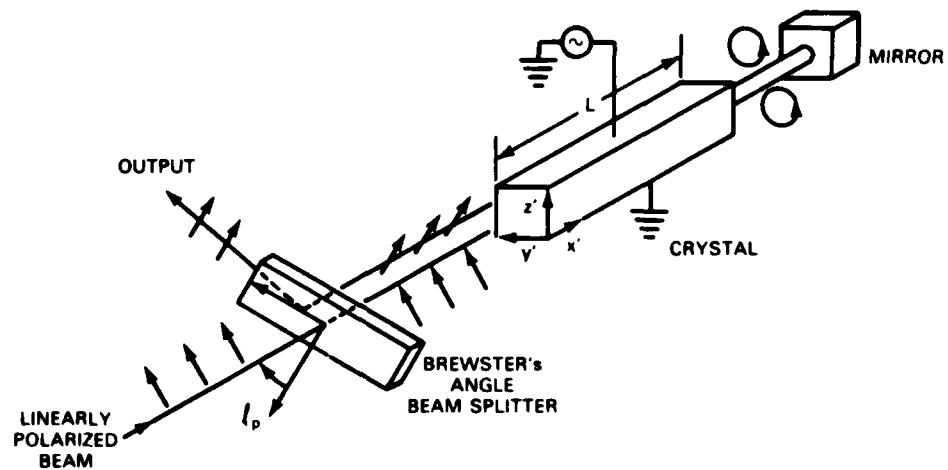


Figure 1. Double Pass Pockels Cell Modulator

A diagram of the experiment is shown in Fig. 2. In a double-pass configuration, the plane-polarized beam passes through the energized Pockels Cell and is converted into two orthogonal components of equal amplitude and 90° relative phase difference. The electric field vector is now circularly polarized. When the circularly polarized light is reflected back through the energized Pockels Cell, it undergoes another 90° phase shift and is transformed back to linearly polarized light, but now perpendicular to the plane of incidence. This polarized beam is reflected off the beam splitter (placed at its polarizing angle) and propagated to the receiver.

Results

The linearly polarized CO_2 TEA laser produces an average of 22 mJ per pulse with an optimum gas mixture. Increasing the laser energy by an order of magnitude will not damage these EO modulator units as they have been reported to operate reliably with 300 mJ CO_2 TEA laser pulses. For pulse code modulation (PCM), a long tapered tail is desirable, and hence a nitrogen-rich mixture is used ($\text{CO}_2:\text{N}_2:\text{He} = 6:18:76$). The resulting waveform is shown in Fig. 3. A telescope is used to reduce the beam to fit through the crystal. A Ge crystal polarizer is used to further increase the linear polarization of the partially polarized laser beam. Detector #1 is the timing detector (HgCdTe) which triggers the modulator electronics. A pulse generator produces a 2 microsecond gate during which a 5 MHz square waveform is generated. This signal drives the high voltage power supply which drives the crystal cell producing an optical signal 100 nanoseconds wide at 5 MHz repetition rate (see Fig. 4 for power supply voltage). The high voltage power supply was manufactured by Cober Electronics and was designed specifically for this application using vacuum tube technology. The modulation optical signal is detected by a reverse-biased HgCdTe PV detector with a frequency response greater than 10 MHz. The received signal is shown in Fig. 5 with two resolutions. Within a 2 microsecond gate, ten 100 nanosecond pulses are created. The finite rise time of approximately 30 nanoseconds is limited by the frequency response of the power supply. A possible alternative to the vacuum tube design that would improve the rise time and hence increase the repetition rate of the modulator might be using an avalanche transistor design for the power supply. The rise time of the CdTe crystal is less than a nanosecond (500 MHz frequency capability) and should not limit the overall frequency response.

Pulse code modulation can be achieved by transmitting a sequence of pulses at 5 MHz; if a pulse is present, a one is indicated, and if a pulse is absent, a zero is indicated. To demonstrate PCM, the repetition rate was changed to 2.5 MHz, or every other pulse was deleted from the pulse train logic. An oscilloscope trace of this particular telegram is shown in

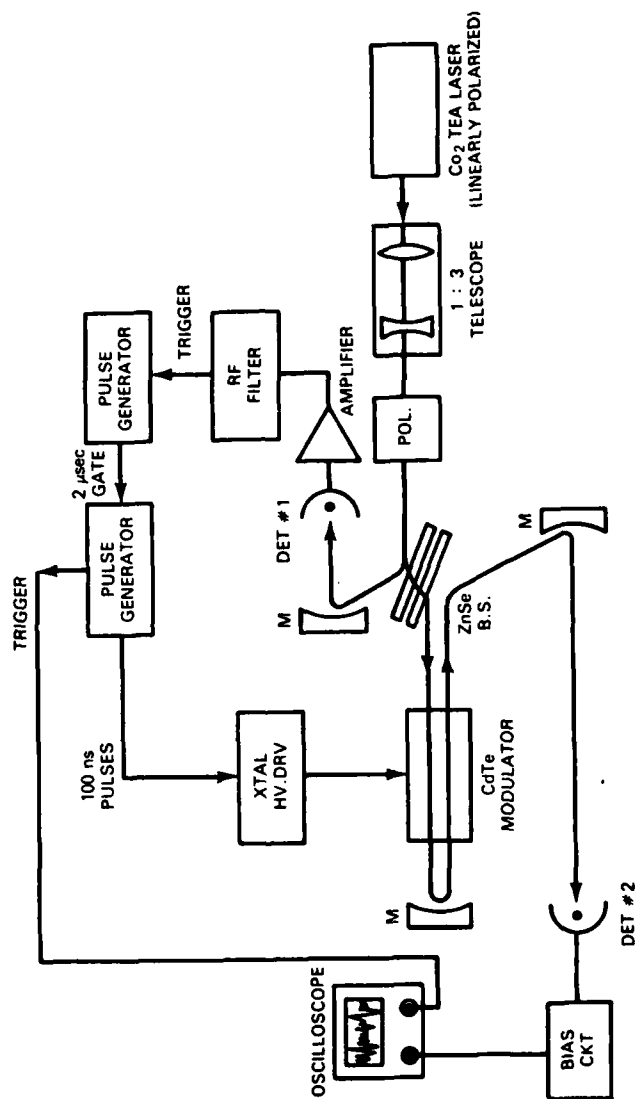


Figure 2. Experiment for PCM of CO₂ TEA Laser

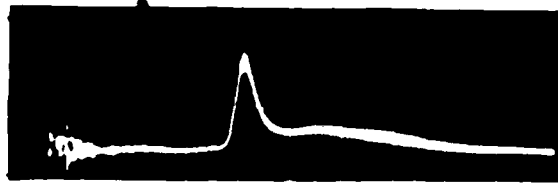


Figure 3. Unmodulated CO₂ TEA Laser Pulse with N₂ Rich Gas Mixture (500 ns/DIV)

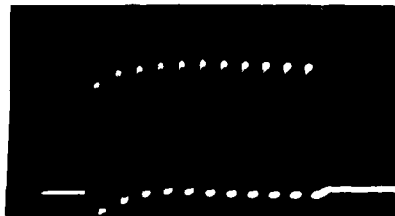


Figure 4. Output Signal of High Voltage Power Supply for CdTe Crystal Modulator (500 V/DIV, 500 ns/DIV)

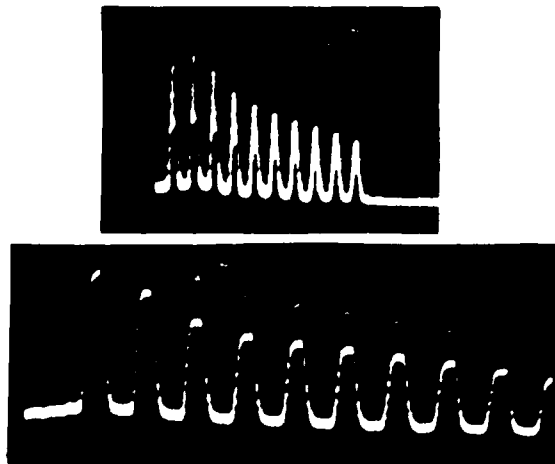


Figure 5. Receiver Signal from Pulse Code Modulation of CO₂ TEA Laser Pulse (Top trace: 500 ns/DIV, 10 mV/DIV; Lower trace: 200 ns/DIV, 10 mV/DIV) Logic: 1111111111

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Fig. 6. Note that the initial pulse is the unmodulated gain-switched spike that has leaked through the polarizers.

In fact, the extinction level of the modulator will depend on this polarization leak-through. Measurement of the zero level of modulation was obtained indirectly by comparing the unmodulated signal due to polarization leak-through and the modulated signal at its zero level. By examining Figs. 7 A and B, which are sequential shots of the unmodulated and modulated signal, the extinction appears to be 100%. When averaged over several oscilloscope traces, the zero level coincided with the unmodulated signal level indicating 100% extinction. The issue of signal extinction is important to CBIFF if confidence in the transmitted signal is to be maintained. In a dynamic atmospheric environment such as fog, rain, dust, and smoke, the detection threshold is required to be set at the minimum allowable level so as to obtain the largest dynamic detection range possible. By insuring a 100% extinction of the signal, the threshold can be set as low as possible.

Beam quality was determined by measuring the horizontal intensity profile of the output beam with and without the crystal modulator in the optical train. Ten independent pulses were averaged for each position across the beam in increments of 0.9 milliradians. The average signal normalized to the peak average signal is plotted in Fig. 8 with and without the effects of the crystal. The results indicate substantial beam degradation initially from the beam splitters due to multiple reflections, and some further degradation by the CdTe crystal. Beam degradation by multiple reflections can be minimized by using a single, wedged beam splitter instead of parallel surface beam splitters such that the internal reflections produce highly diverging wavefronts. The calculated beam divergence for a Gaussian beam is given by the following equation:

$$\theta = \frac{4}{\pi} \frac{\lambda}{D} \quad (3)$$

Using the aperture of the Pockels Cell unit as the limiting case, $D = 3$ mm, the beam divergence ($\theta/2$) is 2.75 mrad, much less than what was observed in Fig. 8. The additional beam spread can be attributed to multiple reflection. Beam quality after the telescope was not measured although burn patterns indicate a symmetric beam unlike that measured after the beam splitters.

Conclusion

In conclusion, we have demonstrated pulse code modulation of the tail of the CO_2 TEA laser pulse at a 5 MHz repetition rate with a 100% depth of modulation using an external double-pass Pockels Cell modulator. Each

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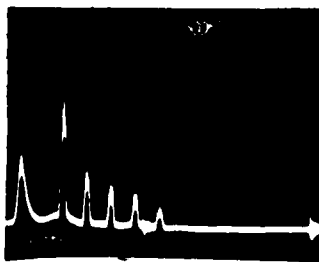


Figure 6. Pulse Code Modulation
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(500 ns/DIV)

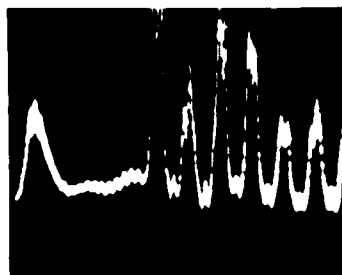
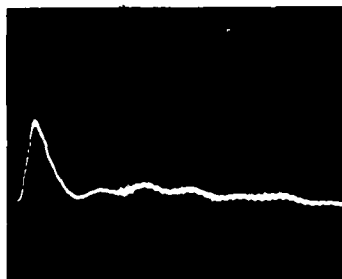


Figure 7. Extinction Level Measurement. Two Sequential Oscilloscope Traces (Top trace: unmodulated, 200 ns/DIV; Lower trace: modulated, 200 ns/DIV)

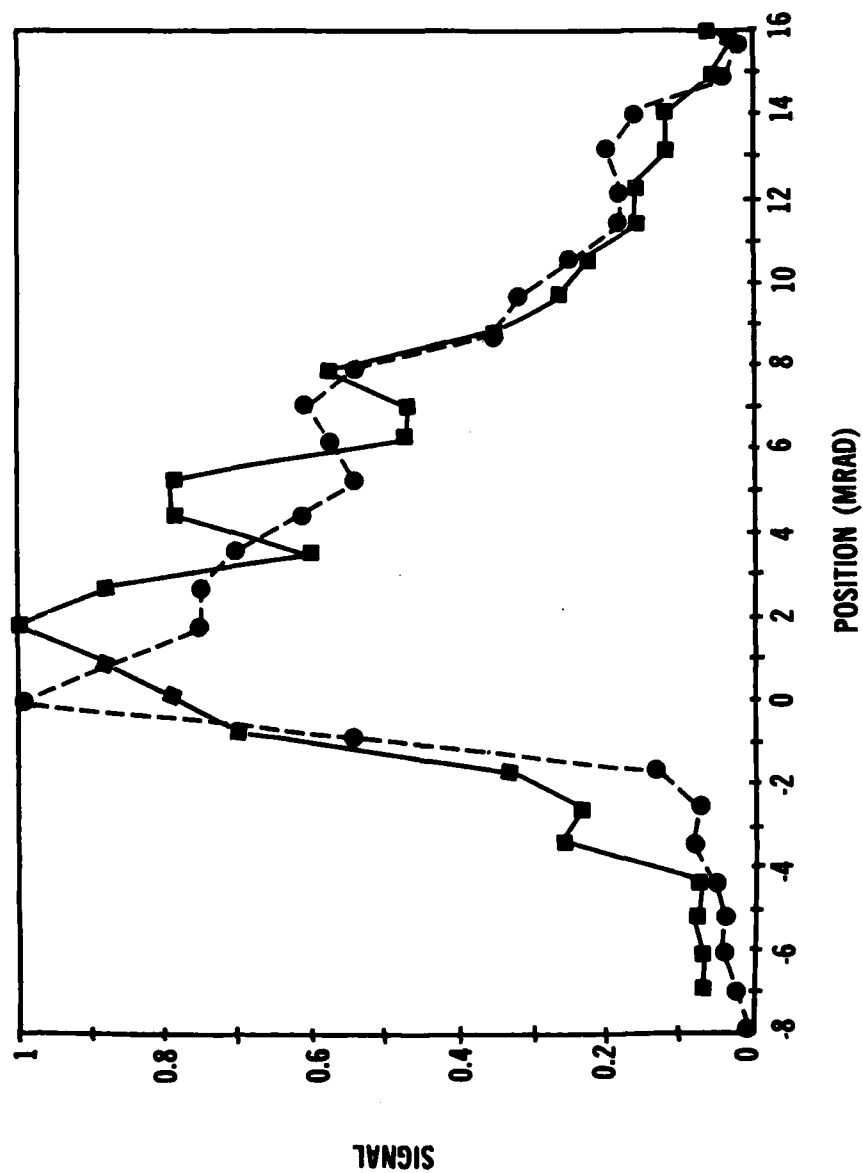


Figure 8. Horizontal Beam Profile of Pulse Code Modulator. Squares represent output with the Pockels Cell, and dots are without the cell.

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pulse is approximately 100 nanoseconds wide with a rise and fall time of approximately 30 nanoseconds. With a 100% depth of modulation, a high false alarm rate under dynamic battlefield induced transmission conditions is prevented.

This device can extend the capabilities of a CO₂ TEA laser rangefinder to CBIFF applications by using the tail for sending encoded telegrams to the target and shaping the gain-switched spike to improve ranging accuracy. Therefore, a multifunctional device has been conceptually demonstrated to provide both precision range finding and information transfer from the transmitter to the receiver. The multifunctional device concept can be applied to all EO devices to provide a cost effective method to improve and extend performance capabilities.

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2. Longhurst, R. S., "Geometrical and Physical Optics", Longman, (1973).
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